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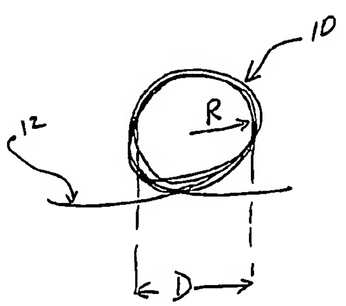
(54) Title: REDUCED CLAD DIAMETER RARE EARTH DOPED FIBER COILS AND OPTICAL AMPLIFIERS UTILIYING SUCH COILS

(57) Abstract: According to the present invention, a rare earth doped fiber coil comprises a rare doped optical fiber having a rare-earth doped core surrounded by a cladding. The outer clad diameter is less than 100μm. The rare earth doped optical fiber has a length of 10 m to 50m and is coiled with abend radius of less than 40mm.



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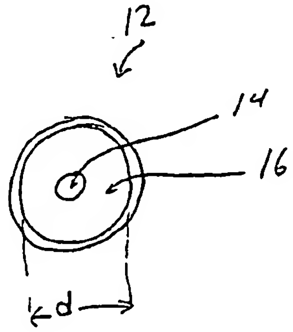

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Reduced Clad Diameter Rare Earth Doped Fiber Coils and Optical Amplifiers Utilizing Such Coils

Background of the Invention

Cross-Reference to Related Applications

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 60/459,842, filed April 1, 2003, entitled "Reduced Clad Diameter Rare Earth Doped Fiber Coils and Optical Amplifiers Utilizing Such Coils."

Field of the Invention

[0002] The present invention relates generally to optical rare-earth doped fibers with small clad diameters and, more specifically, to coiled or bent optical rare-earth doped fibers with small clad diameters.

Technical Background

[0003] Rare earth doped optical fibers are commonly utilized in optical amplifiers. An example of optical amplifier is an erbium doped optical fiber amplifier (EDFA). A typical erbium doped fiber has an outer clad diameter of 125 μm. When this type of fiber is coiled such that bend radius is small (35 mm or smaller), the fiber coils suffer from bend-induced birefringence. The tighter (smaller) the bend radius, the higher the amount of bend-induced birefringence. More specifically, the bend-induced birefringence is inversely proportional to the square of the bend radius. The bend induced birefringence results in Differential Group Delay or DGD. As illustrated in Figure 1, the smaller the bend radius, the greater the DGD. That is, due to bend-induced birefringence one polarization component of the optical signal propagates through the fiber faster than the other polarization component. As a result, because Polarization Mode Dispersion or PMD is the average of DGD values over the wavelength band, the bend induced birefringence also results in increased PMD. This is especially problematic in high data rate amplifiers because PMD broadens the signal pulse width, thereby limiting the error-free bit rate of a fiber optic transmission system. Thus, DGD

and PMD are limiting factors that prevent utilization of smaller coil diameters in high data rate optical amplifiers.

SUMMARY OF THE INVENTION

[0004] According to the present invention, a rare earth doped fiber coil comprises a rare earth doped optical fiber having a rare-earth doped core surrounded by a cladding. The outer clad diameter is less than 100μm. The rare earth doped optical fiber has a length of 10 m to 50m and is coiled with a bend radius of less than 40mm.

[0005] According to one embodiment, the rare earth doped optical fiber is an Er doped optical fiber.

[0006] According to one embodiment, the bend radius is between 8mm and 20mm.

[0007] According to one embodiment, the outer clad diameter is between 70μm and 95μm.

[0008] One advantage of the present invention is that the coiled optical fiber exhibits reduced DGD and PMD while utilizing lesser amount of glass to manufacture. Furthermore, the same length fiber may be packaged in a smaller volume, thus reducing the overall size of optical amplifiers. Consequently, the present invention may be utilized, for example, to manufacture optical amplifiers in significantly smaller packages or with ultra-low PMD.

[0009] Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0010] It is to be understood that both the foregoing general description and the following detailed description present exemplary embodiments of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description, serve to explain the principles and operations of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is an illustration of differential group delay DGD dependence on bend radius R;

[0012] Figure 2 is a view of one embodiment of the present invention;

[0013] Figure 3 is a cross-sectional view of the optical fiber illustrated in Fig. 2;

[0014] Figure 4 illustrates the relationship between DGD and the outer clad diameter of two optical fibers with identical compositions; and

[0015] Figure 5 illustrates fiber profile of an exemplary rare earth doped fiber.

[0016] Figure 6 is a schematic of an optical amplifier that utilizes the fiber coil depicted in Fig. 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Whenever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts.

[0018] One embodiment of the reduced clad diameter rare earth doped fiber coil of the present invention is shown in **Figure 2**, and is designated generally throughout by the reference numeral **10**. The fiber coil **10** has a bend radius (illustrated as coil radius R) of less than 40 mm. It is preferable, in order to be more compact while maintaining minimal PMD effects due to birefringence, that the bend radius R be between 8 mm and 35 mm, more preferably between 8 mm and 2 0mm and most preferably between 10 mm and 15 mm. However, if the bend radius R becomes too small (i.e. less than 5mm), then fiber bend loss increases and, even more importantly, fiber reliability may suffer, i.e. fiber life span may be shortened.

[0019] As embodied herein and depicted in **Figure 3**, this fiber coil **10** comprises a rare earth doped optical fiber **12** having a rare-earth doped core **14** surrounded by a cladding **16** with outer clad diameter d of less than 100μm. It is preferable that the outer clad diameter d be in the range of 70μm to 95μm, more preferably in the range of 72μm to 90μm, and even more preferably in the range of 75μm to 85μm. The rare earth doped optical fiber has a length L of 10m to 50m and, when utilized in optical amplifiers, it is

often preferred that its length be in the 10 to 30m range. If the outer clad diameter d becomes too small (i.e., less then 70μm), the fiber may become more difficult to handle, less strong and more sensitive to perturbations such as microbending.

[0020] Bend induced birefringence, DGD and PMD are all proportional to the square of the outer clad diameter d. Therefore, a reduction in a size of outer clad diameter from 125 μm to 80 μm should result in $(80/125)^2=0.41 \times$ PMD of the identical composition fiber with a 125 μm outer diameter, or a 59% reduction in PMD. Similarly, a 90 μm outer clad diameter should have only $0.52 \times$ PMD of the identical composition fiber with a 125 μm outer diameter, or a 48% reduction in PMD.

[0021] **Figure 4** illustrates the relationship between DGD and the outer clad diameter of two exemplary optical fibers. Specifically, the vertical axis of **Figure 4** represents DGD (measured in fs). The horizontal axis is an inverse square of the fiber's outer clad diameter ($1/d^2$), in units of mm^{-2}. These measurements shown in Figure 4 were performed using 20 m long fiber coils of various radii R. In these measurements, coil radii R were between 5 mm and 10 mm. Results for a rare earth doped fiber (Er doped fiber) with an outer clad diameter d=125 μm is denoted by line A. Another rare earth doped fiber with identical composition, but reduced clad diameter d=80 μm is denoted by line B. **Figure 4** clearly shows that fiber B suffers from much smaller amount of DGD than fiber A. The reduction in PMD is approximately consistent with the above calculation.

[0022] The exemplary fibers A and B have the following core composition: 8.6 wt% Al_2O_3, 13.6 wt%GeO_2, 700 wtppm Er_2O_3. The fiber profile is illustrated in **Figure 5**. The claddings of these fibers is made of silica.

[0023] However, because DGD and PMD are proportional to a square of the fiber's outer clad diameter, as shown above, then regardless of fiber's composition, a reduction in the clad diameter of any coiled rare-earth doped optical fiber will result in better DGD, PMD and smaller package volume. The latter attribute is especially useful for reducing the overall size of optical amplifiers.

[0024] As embodied herein and depicted in **Figure 6,** an optical amplifier **20** may utilize rare earth doped fiber coil **10** as its amplification medium. In this exemplary amplifier, coil **10** is pumped by the pump source **22** (laser diode, for example) that is coupled to the rare-earth doped fiber **12** by an optical coupler **24**. The optical coupler

24 provides both incoming optical signal S and the pump light from the pump source 22 to the rare earth doped fiber 12, which amplifies incoming signal S and provides, as an output, the amplified signal S'. Optionally, in order to provide additional pump power, another pump source 22' may also be coupled to the rare-earth doped fiber 12 via an additional optical coupler 24'.

[0025] As stated above, the rare earth doped amplifying fiber 12 of coil 10 has a rare earth doped core 14 surrounded by a cladding. The outer clad diameter d is less than 100 μm, preferably less than 95 μm, more preferably 90 μm or less, and most preferably 75 μm to 85 μm. The length of the rare earth doped optical fiber 12 is 10 m to 50 m and the bend radius is less than 40mm. It is preferred that the bend radius R be 35 mm or less, and more preferably 10mm to 20 mm.

[0026] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A rare earth doped fiber coil, said rare earth doped fiber coil comprising:

a rare earth doped optical fiber having a rare-earth doped core surrounded by a cladding with outer clad diameter of less than 100μm, said rare earth doped optical fiber having a length of 10 m to 50m and being coiled with a bend radius of less than 40mm.

2. The rare earth doped fiber coil according to claim 1, wherein said clad diameter is in the range of 70μm to 95μm.

3. The rare earth doped fiber coil according to claim 1, wherein said clad diameter is in the range of 72μm to 90μm

4. The rare earth doped fiber coil according to claim 1, wherein said clad diameter is in the range of 75μm to 85μm.

5. The rare earth doped fiber coil according to claim 1, wherein said rare earth doped optical fiber is an Er doped optical fiber.

6. The rare earth doped fiber coil according to claim 5, wherein said bend radius is between 8mm and 35mm

7. The rare earth doped fiber coil according to claim 5, wherein said bend radius is between 8mm and 20mm.

8. The rare earth doped fiber coil according to claim 5, wherein said bend radius is between 10mm and 15mm.

9. The rare earth doped fiber coil according to claim 1, wherein said bend radius is between 8mm and 20mm.

10. The rare earth doped fiber coil according to claim 1, wherein said bend radius is between 10mm and 15mm.

11. An optical amplifier comprising: a length of rare earth doped amplifying fiber, said amplifying fiber having a rare-earth doped core surrounded by a cladding with outer clad diameter of less than 100μm, said rare earth doped optical fiber having a length of 10 m to 50m and being coiled with a bend radius of less than 40mm.

12. The optical amplifier according to claim 10, wherein said rare earth doped optical fiber is an Er doped optical fiber.

13. The optical amplifier according to claim 10, wherein said bend radius is between 8mm and 20mm.

14. The optical amplifier according to claim 10 wherein said clad diameter is between 70μm and 95μm.

15. The optical amplifier according to claim 10 wherein said outer clad diameter is between 72μm and 90μm.

16. The optical amplifier according to claim 10 wherein said outer clad diameter is between 75μm and 85μm.

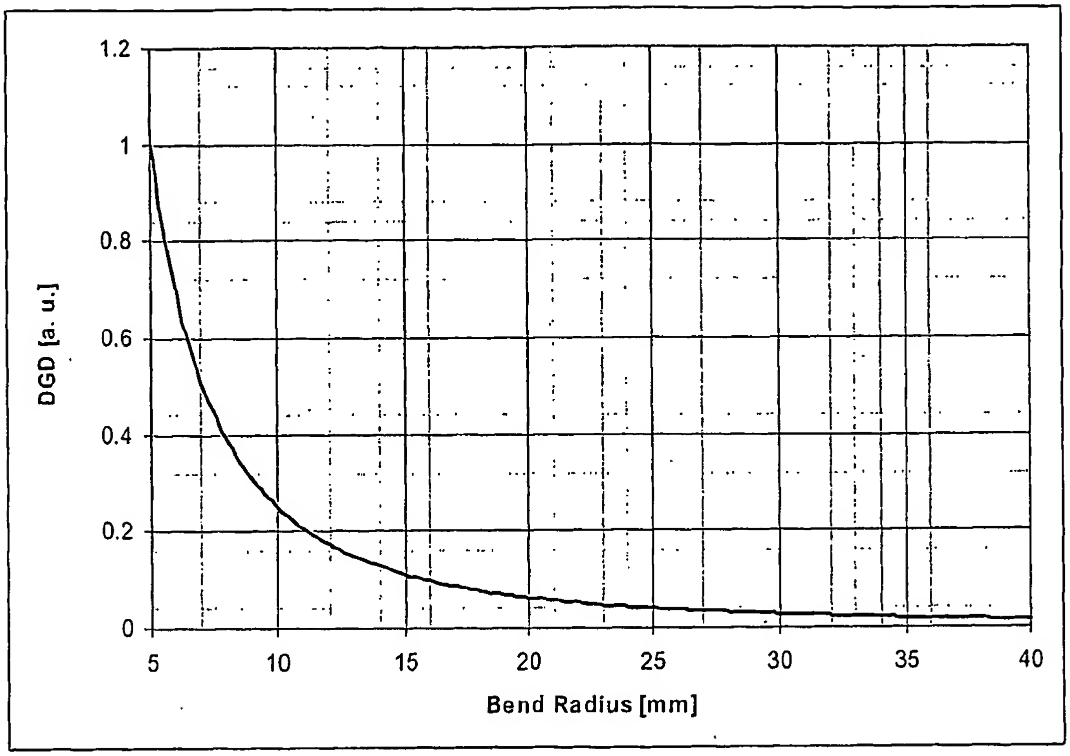

Figure 1

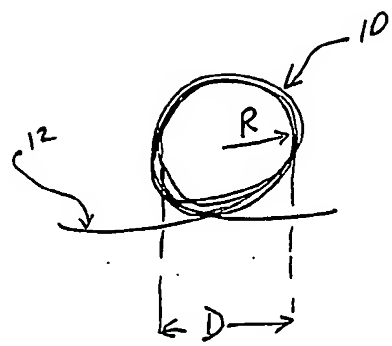

Figure 2.

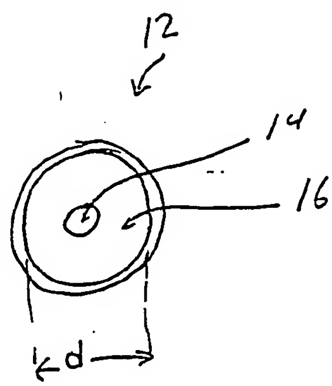

Figure 3

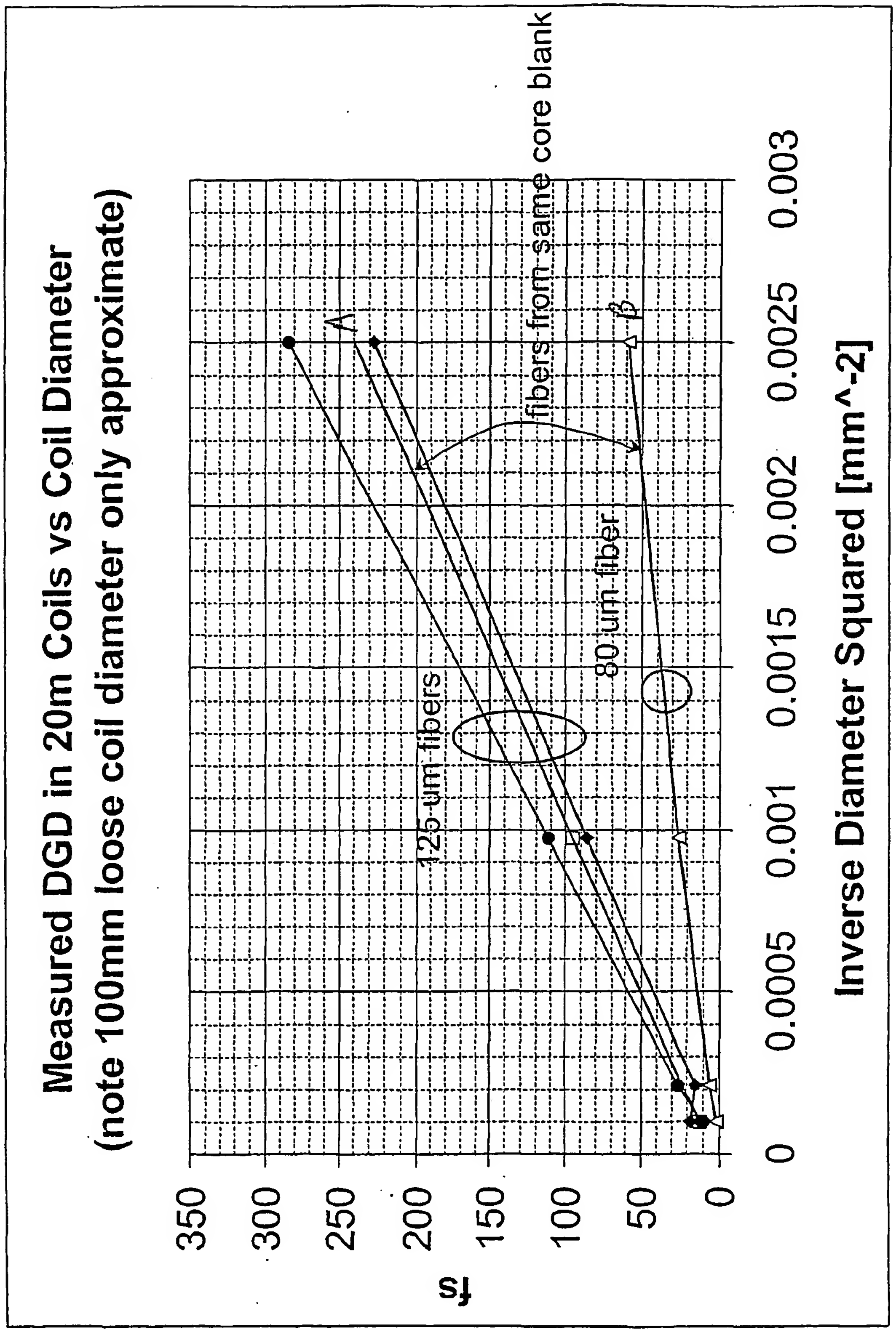
Measured DGD in 20m Coils vs Coil Diameter
(note 100mm loose coil diameter only approximate)
fs
350
300
250
200
150
100
50
0
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
Inverse Diameter Squared [mm^-2]
125 um fibers
80 um fiber
fibers from same core blank
A
B

Fig. 4

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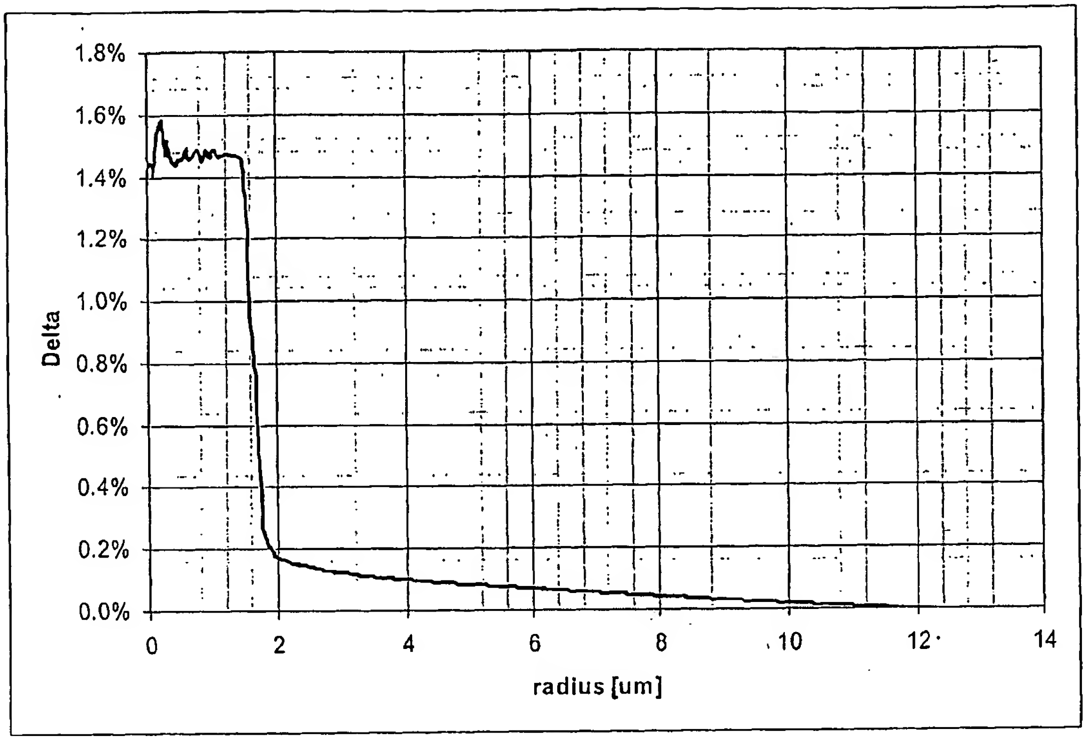

Figure 5

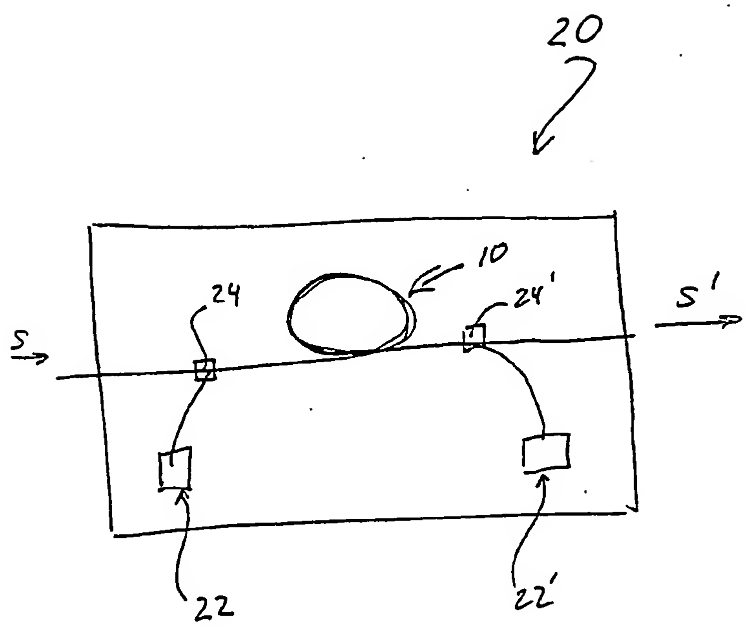

Figure 6

INTERNATIONAL SEARCH REPORT

national Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01S3/067

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 03/012489 A (CORNING INC) 13 February 2003 (2003-02-13) page 5, paragraph 27 page 8, paragraph 0038 page 9, paragraph 39; figure 3	1
A	the whole document	2-16
A	WO 00/43816 A (CORNING INC) 27 July 2000 (2000-07-27) abstract; figure 13	1-16
A	EP 0 442 553 A (PIRELLI CAVI SPA) 21 August 1991 (1991-08-21) page 6, line 6 - line 9	1-16
A	US 6 496 301 B1 (KLINER DAHY ET AL) 17 December 2002 (2002-12-17) column 12, lines 52,55,63	1-16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
21 July 2004	02/08/2004

Name and mailing address of the ISA	Authorized officer
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ational Application No
'/US2004/008097

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/011876 A1 (FIDRIC BERNARD G) 16 January 2003 (2003-01-16) column 3, paragraph 27; figure 5	1-16
A	EP 0 637 762 A (FUJIKURA LTD) 8 February 1995 (1995-02-08) page 7, line 26 - line 29	1-16
A	US 6 434 295 B1 (DOMINIC VINCENT G ET AL) 13 August 2002 (2002-08-13) column 6, line 53 - column 7, line 8	1-16
A	WO 02/101889 A (CARTER ADRIAN ; NUFERN (US)) 19 December 2002 (2002-12-19) page 8, line 2 - line 8	1-12
A	US 6 480 659 B1 (PATLAKH ANATOLY ET AL) 12 November 2002 (2002-11-12) column 8, line 17 - line 20	1-16

INTERNATIONAL SEARCH REPORT

ıational Application No
'/US2004/008097

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 03012489	A	13-02-2003	EP	1421418	A2	26-05-2004
			WO	03012489	A2	13-02-2003
			US	2003035638	A1	20-02-2003
WO 0043816	A	27-07-2000	AU	3582200	A	07-08-2000
			CA	2360933	A1	27-07-2000
			CN	1347511	T	01-05-2002
			EP	1181587	A1	27-02-2002
			JP	2002535715	T	22-10-2002
			TW	419600	B	21-01-2001
			WO	0043816	A1	27-07-2000
			US	6192179	B1	20-02-2001
			US	6429963	B1	06-08-2002
			US	6337763	B1	08-01-2002
EP 0442553	A	21-08-1991	IT	1237980	B	19-06-1993
			AT	119690	T	15-03-1995
			AU	642698	B2	28-10-1993
			AU	7081891	A	15-08-1991
			BR	9100633	A	29-10-1991
			CA	2034797	A1	13-08-1991
			CN	1054137	A ,B	28-08-1991
			CS	9100300	A2	15-09-1991
			DE	69107872	D1	13-04-1995
			DE	69107872	T2	07-09-1995
			DK	442553	T3	24-07-1995
			EP	0442553	A1	21-08-1991
			ES	2072523	T3	16-07-1995
			FI	910649	A	13-08-1991
			HK	2596	A	12-01-1996
			HU	60398	A2	28-08-1992
			IE	910440	A1	14-08-1991
			JP	3239124	B2	17-12-2001
			JP	4298724	A	22-10-1992
			KR	178393	B1	15-05-1999
			NO	910530	A	13-08-1991
			PL	289030	A1	26-08-1991
			PT	96736	A ,B	31-12-1992
			SK	278814	B6	04-03-1998
			RU	2086062	C1	27-07-1997
			US	5161050	A	03-11-1992
US 6496301	B1	17-12-2002	AU	5517301	A	24-09-2001
			EP	1266259	A1	18-12-2002
			WO	0169313	A1	20-09-2001
US 2003011876	A1	16-01-2003	NONE			
EP 0637762	A	08-02-1995	DE	69424606	D1	29-06-2000
			DE	69424606	T2	25-01-2001
			EP	0637762	A1	08-02-1995
			US	5689578	A	18-11-1997
			WO	9419714	A1	01-09-1994
US 6434295	B1	13-08-2002	NONE			
WO 02101889	A	19-12-2002	WO	02101889	A2	19-12-2002

INTERNATIONAL SEARCH REPORT

ational Application No
/US2004/008097

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 6480659	B1	12-11-2002	WO	03042735 A1	22-05-2003

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